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INTRODUCING SYSTEMS DYNAMICS IN NATIONAL PLANNING

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by

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INTRODUCTION

The purpose of this paper is to provide elementary knowledge of Systems Dynamics and to provide a brief indication of its advantages and shortcomings, as an approach to development in planning. The background of Zimbabwe, vis-a-vis the problems being faced by the nation as a whole are pointed out. Systems Dynamics is later introduced to familiarize readers with the concepts, and the need for its application in national planning is highlighted. The paper then brings out the advantages and disadvantages of using Systems Dynamics in the planning of the economy.

It is to be emphasized that Systems Dynamics is not a substitute for conventional economic analysis, but that both approaches could be used to come up with more effective plans.

COUNTRY BACKGROUND

The population of Zimbabwe as of June 1987 was estimated to be about 8,6 million people and is growing by an estimated rate of 2,8% per annum. Should the birth rate remain near present levels, the population is likely to double itself in about 20 years, time. In a nation such as Zimbabwe, where development effort is built around the goal of meeting basic human needs, population factors can be critical to the ability of the country to achieve its social and economic objectives. The continued high growth rate will exert pressure on goods and services such as food, housing, education, health and natural resources such as wood, electricity and coal. Population exerts a considerable influence on economic development, accelerating or retarding it, and in the Zimbabwean case it retards the situation. The growth of Zimbabwe's population of 2,8% far exceeds that of the economy. The drought, which we cannot control, has a great influence on the Gross Domestic Product (GDP). For instance, in 1980-81 the economy was buoyant largely because of successful harvests. In 1982-83 the economy suffered from drought and the world recession. This aggravated the balance of payments situation, which fostered a cyclical effect, aggravating the economic situation. In 1985 the economy experienced a high real growth rate of about 8%. This good performance was primarily agriculture driven, following the good rainy season of 1984/85. However, in 1987 the GDP grew less than 1% (i.e. 0,3%) as a result of the adverse effects of the dry season.

Table 1
GROSS DOMESTIC PRODUCT (% CHANGES)

	1981	1982	1983	1984	1985	1986	1987
Agriculture & Forestry	14.1	-7.2	-15.7	23.1	23.8	-5.01	8.7
Mining & Quarrying	-2.5	2.2	-1.4	3.9	-1.0	1.7	2.4
Manufacturing	9.9	-0.5	-2.9	-5.0	11.5	3.0	2.2
Electricity & Water	0.0	-10.0	7.9	2.9	12.9	19.0	30.9
Construction	15.4	-3.8	-7.9	-7.5	-25.6	3.1	6.1
Finance & Insurance	9.4	19.5	-2.4	-6.9	-1.1	0.5	3.7
Real Estate	0.0	0.0	2.3	0.0	0.0	2.3	0.0
Distrb. Hotel & Res	1.1	1.1	-131	-6.6	5.5	5.2	1.5
Transport & Commun.	4.7	2.3	-0.9	0.9	4.9	0.8	9.2
Public Administration	16.5	-1.8	1.5	7.7	2.2	0.0	6.2
Education	39.6	20.3	9.2	8.1	6.9	4.7	7.2
Health	7.0	15.8	1.1	4.5	4.3	9.3	4.7
Domestic Services-	3.1	-3.2	-1.6	-1.7	1.7	0.0	8.3
Other Services	7.5	9.7	5.4	0.9	8.3	6.4	5.2
Less Imputed Bank Chg	-1.9	6.6	-0.9	-6.3	9.5	-5.2	-3.7
GROSS DOMESTIC PRODUCT	9.7	1.4	-3.6	2.3	7.6	2.3	0.3

Source: CSO *Quarterly Digest of Statistics* - September 1988

Very little investment has taken place in the country leading to unemployment, which is a major problem facing Zimbabwe. As of 1982, the labour force was estimated at 2,5 million people, including approximately one million communal farmers. Of the remainder, about 1 045 900 people worked in the formal sector (See Table 2), about 100 000 in the informal sector and about 12% (or 300 000 people) were unemployed. By late 1987 the number of unemployed was estimated to have increased to 570 000 or about 18% of the labour force of 3,2 million. The number of school-leavers looking for jobs is increasing every year, adding more to the unemployed. About 90 000 school-leavers are said to join the employment market every year.

It follows that those yet to be born will certainly be delivered on to the large odious arena of unemployment.¹

1 *The Sunday Mail*, January 8, 1989, p.8.

Table 2
EMPLOYMENT

YEAR.NO.	OF EMPLOYEES%	CHANGE
1980	1 000 900	-
1981	1 037 700	2,8
1982	1 045 900	0,8
1983	1 033 400	-1,2
1984	1 036 400	0,3
1985	1 042 500	0,6
1986	1 071 300*	2,8
1987	1 100 100*	2,7
1988	1 128 900*	2,6
1989	1 157 700*	2,6
1990	1 186 500*	2,5

Source: CSO *Quarterly Digest of Statistics* - September 1988

* - Estimates

In addition to unemployment, urban dwellers are faced with the problem of accommodation. The total housing demand for both urban and rural dwellers in 2000 is estimated to be 1,9 million units. This implies an annual production of 130 000 housing units. The annual rate of increase of the backlog of housing units was estimated to be about 15% (i.e. 112 000 units). Yet during the years of the transitional plan only 500 new houses were built per year. The faster the population grows, the more quickly people will be attracted to the big cities, such as Harare and Chitungwiza, and the faster the services and living standards will come under stress and strain, affecting the quality of life. The housing shortage is aggravated by the construction industry where there is the shortage of building materials, lack of foreign currency for the purchase of new plant, equipment and spares, as well as shortage of skilled manpower and transport. Crowded and squatter settlements are always the result and are a health hazard leading to malnutrition and contagious diseases.

The Ministry's plan is to train a total of 12 500 health workers by the year 1993 i.e. one Village Health Worker for every 500 people in the rural areas. By 1984 4 417 VHWs had been trained. Nutritional deficiencies and diseases associated with poverty are common among Zimbabweans. Studies indicate that in the rural areas up to 60% of the children show evidence of malnutrition. Diseases such as diarrhoea, pneumonia, measles, tetanus, malaria and tuberculosis continue to be widespread. Problems associated with pregnancy, childbirth and the new-born period are also common. Assuming that one rural centre will serve 8 000 residents, 275 new centres would be needed by the year 2000 to provide minimal primary health care.

On education - about 20% of central government expenditure in 1984/85 was allocated to education. If population growth rates remain unchanged, the number of primary school pupils would double from 2,2 million in 1985 to 4,2 million in 2015. Twice as many teachers would be required, as well as the current number of classrooms. Secondary school enrolment is expected to more than triple to almost one million pupils by 2015.

As a result of inadequate levels of direct foreign investment, the overall reduction in capital inflows from commercial and official developed sources over the past few years and in the

light of the country's commitment to fully servicing the external debt, the country has progressively become a net capital exporter as repayments of foreign loans are now larger than the amount of foreign exchange coming into the country from new borrowing and foreign investment.

Limited foreign currency continues to create shortages in certain products such as spare parts for machinery and vehicles, tyres, soap, detergents, rice and salt. This results in upward pressure on the prices of some consumer items, particularly those with a higher import content.

The resources on which we depend are slowly getting depleted. Wood is extremely important for the rural population of Zimbabwe as a source of energy and building materials. Eighty per cent of the country's population use wood for cooking and heating.

The TNDP says:

High population growth, density of settlement and demand for agricultural land and serious shortages of forest and tree plantations are likely to cause serious shortages of fuelwood in the future. At present 2,5 million people in the communal areas suffer from a critical energy shortage . . . Twenty-seven districts have been described as critically short of fuelwood and the position is deteriorating rapidly.²

Land resettlement schemes were instituted by Government to ease pressure on land. Of the target of 162 000 families set to be resettled in 1982, only 40 000 have been resettled. The increasing backlog in the number of families to be resettled results from other constraints in addition to a growing population. The increasing pressure on land of a population currently growing at an annual rate of 2,8% poses a serious threat to any economic gains the current development trend may stand to achieve. Land erosion is also on the increase especially in communal areas, "robbing us of yet another important resource - soil".³

By 1986, all the problems described earlier had combined to reduce real economic growth to only 2,3%, a rate much lower than the estimated population growth rate of 3%. Planning in Zimbabwe has failed in the past years with targets never being achieved. It is well appreciated that one cannot separate demographic from economic growth and treat them independently. These have to be looked at as a whole, not as a series of separate issues.

To sum up, to a very large extent it is possible to control our population so that its growth runs concurrently with the economic growth. The nation has not been able to keep the economic growth above the 2,8% population growth. Population growth has more often than not outstripped economic growth since independence mainly because of the effects of drought, recession and certain inherited imbalances in the economy. Instead the economic growth has even gone negative. This will create problems in that the economy will not be able to cope with the increasing population, thus leading to inadequate health, educational facilities, shortage of food and accommodation, etc. What we can do as a nation is to try and control our population and in the meantime trying to achieve a higher economic growth.

2 TNDP, Vol. 1.

3 *The Sunday Mail*, January 8, 1989, p.8.

The Minister of Finance, Economic Planning and Development, Dr. Bernard Chidzero, has been quoted as saying:

... the Government was now finalising a major economic policy programme aimed at ensuring economic growth, but at the same time the men and women of Zimbabwe should also play their role by putting brakes on population growth".⁴

Thus family sizes on the other hand have to be limited with a view to reducing the rate of growth of population so that population growth is in harmony with economic growth.

To conclude this section, the background of the country, i.e. population and socio-economic factors, has been briefly discussed in order to highlight some of the problems being faced by the nation as a whole. If no remedial action is taken the economy will continue to contract further to a negative growth in GPD while population will continue to increase. It is therefore suggested that a systems dynamics approach be introduced in planning the economy to interact population, resources, environment and economic development, which is not being done by the current plans.

SYSTEMS DYNAMICS

What Is Systems Dynamics?

A system can be regarded as a set of interacting elements responding to inputs to produce outputs.⁵

The Systems Dynamics approach applies to dynamic problems arising in feedback systems.

We assert that organizations, economies, societies ... in fact, all human systems are feedback systems. Viewing them as such provides great leverage for understanding societal problems.⁶

There are several stages in approaching a problem from the Systems Dynamics perspectives:⁷

1. Problem Identification and Definition
2. System Conceptualization
3. Model Formulation
4. Analysis of Model Behaviour
5. Model Evaluation
6. Policy Analysis
7. Model Use or Implementation

The process begins and ends with understandings of a system and its problems.

To conclude this section, important properties of Systems Dynamics problems are that they contain quantities that vary over time, that the forces producing this variability can be

4 *The Herald*, January 9, 1989, p.1.

5 NCC, "Introducing Systems Analysis and Design", p.15.

6 Richardson, G. P. & Pugh III, A. L., "Introduction to Systems Dynamics Modelling with DYNAMO", p.1.

7 *Ibid.*, p.16.

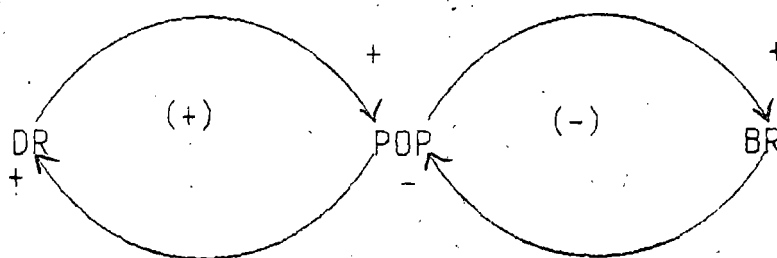
described causally and that important causal influence can be contained within a closed system of feedback loops.

Causal or Feed Back Loops

Feedback is the transmission and return of information.⁸

Since every economic activity has resource consequences which impact upon the needs and upon the environment, the structure must reflect the feedback effects involved. When diagrammed as in Figure 1, feedback systems characteristically form loops of interconnections - loops of causes and effects. Causal-loop diagrams are used most often in the early stages of model conceptualization.

Figure 1 - Example 1
POPULATION DYNAMICS: CASUAL-LOOP DIAGRAM



Where BR = Birth Rate (Number of births per year)
DR = Death Rate (Number of deaths per year)
POP = Total Population

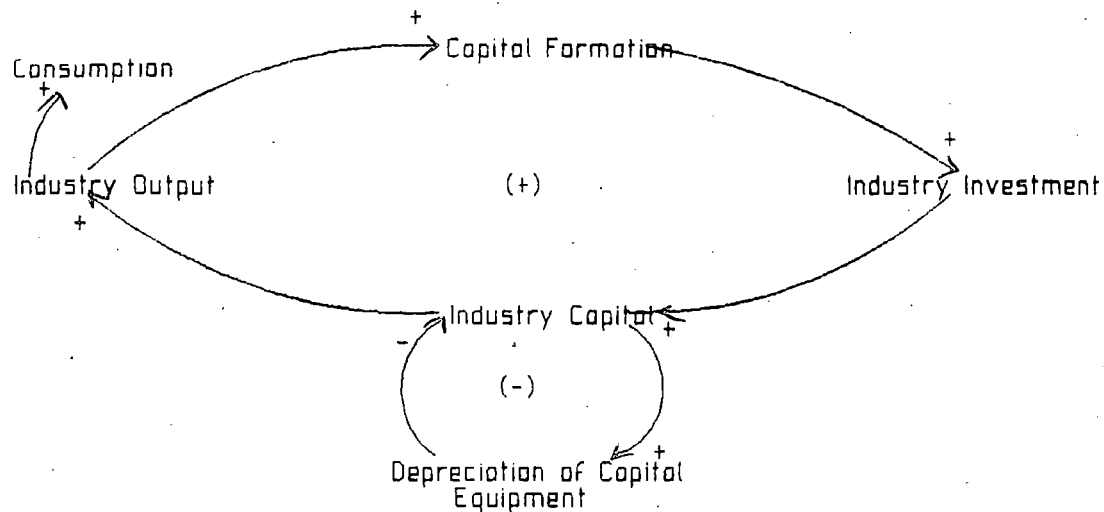
The causal-loop diagram indicates that the total population is related to birth and death rates, both of which vary with the total population. In a causal loop the arrow indicates the direction of the causation; the sign indicates the nature of causation (see Figure 1). A plus sign indicates that the variable at the opposite end of the arrow tends to move in the same direction while a minus sign indicates an inverse relationship between birth rate and

8 Wiener (1961), p.96.

population, i.e. the more people there are the more births whilst death rate and population are inversely related i.e. the larger the population, the more deaths will occur.

The sign of a feedback loop is the algebraic product of the signs of its links. Thus a feedback loop is positive if it contains an even number of negative causal links, and a feedback loop is negative if it contains an odd number of negative causal links.

Figure II - Example 2
Industry Causal-Loop Diagram



- The more industry capital the more the aggregated industrial output.
- An increase in output leads to an increase in capital formation and consumption.
- The more capital formation the more the investment. The more investment in industry the more industrial output.

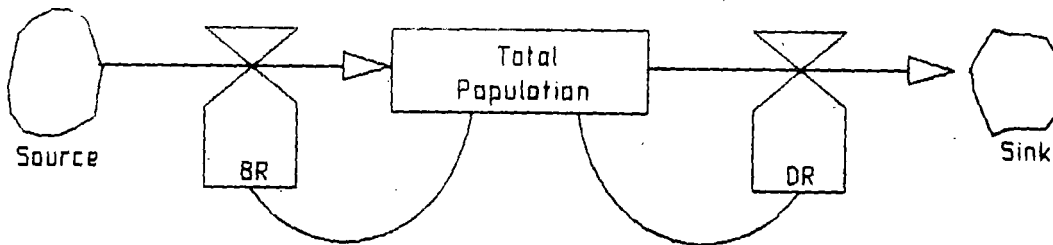
Flow Diagrams

Flow diagrams are used in the advanced stages of model conceptualization. A flow diagram is a more detailed representation of the feedback or causal-loop diagram Richardson and Pugh write:

The Systems Dynamics approach takes the simplifying view that feedback systems involve continuous, fluid-like processes.⁹

⁹ Richardson & Pugh, "Introduction to Systems Dynamics Modelling with DYNAMO", p.31.

Figure III
Flow diagram showing conventional symbols for levels and rates.



Accumulations in feedback loops are called levels. In the Population Dynamics example, Total Population is treated as the level (see Figure III). The flows increasing and decreasing a level are referred to as rates. The cloud-like symbols represent "sources" and "sinks" for whatever is flowing into and out of the level.

The solid arrow shows the flow of people from the source into the level (population). The arrow on the right shows the flow of people into a sink, through death. The dotted arrows show that the size of the population affects the number of births and deaths, or that there is a cause-and-effect link between population, births and deaths.

Types of Equations

Once a causal-loop and a flow diagram have been constructed, the next stage in model conceptualization is to write down the equations in DYNAMO language (The word DYNAMO comes from Dynamic Modelling).

Variables and Constants

All quantities appearing in DYNAMO can be grouped into constants and variables. All variables are written with time subscripts: K, J, KL or JK. Constants are written without timescripts. Thus POP.K represents a varying number of people while POP (without a

timescript) would represent a constant population. A constant acquires its value in a DYNAMO model in a statement labelled on the left with a C.

Level Equations

A variable that accumulates over time is a level variable, and in DYNAMO the equation in which the accumulation is computed is called a level equation.¹⁰

The level equation for population can be written as follows:

$$L POP.K = POP.J DT * (BR.JK - DR. JK)$$

where:-

POOP = country's population (people)
BR = birth rate (people/year)
DR = death rate (people/year)
* = multiplication sign

The above equation is interpreted as follows:-

The population at the present time (i.e. the time currently being calculated) equals the population one time interval earlier, plus the net births that occurred over the interval.

Rate Equations

Richardson and Pugh write:

The variables representing the inflows and outflows in level equations are usually computed in equations terms, rate equations and designated in DYNAMO by the letter R.¹¹

An example is the rate from the population dynamics model:

$$R BR. KL = POP.K * BRF$$

where:

BR = birth rate fraction (people per year) (number of births per person per year) POP = population (people)
BRF = (% increase in births per year)
R DR. KL = POP.K / ALT

where:

DR = death rate
ALT = Average Life Time

¹⁰ *Ibid.*, p.76.

¹¹ *Ibid.*, p.79.

Auxiliary Equations

It would appear that formulating a model in DYNAMO requires identifying the variables that will be modelled as levels, determining their rate equations and assigning values to all the constants appearing in these equations. Usually, however, it is very difficult to write a rate equation for a level without first doing some other algebraic computations, capturing information needed in the formulation of the rate equation. These algebraic computations in DYNAMO are termed auxiliary equations.¹²

By definition an auxiliary equation is a computation representing information in a feedback system. Auxiliaries aid in the formulation of rate equations. An auxiliary equation in DYNAMO is designated by the letter A.

Table Functions

When a non-linear relationship is required, a table function in DYNAMO is used to capture the relationship. Points are specified i.e. the maximum, minimum and the increment of points on the x-axis and the successive y-values, e.g. $BR.K = TABHL(BR1, TIME.K, 1982, 2032, 10)$

$T BRT = 40$

N. Equations

All equations appearing in DYNAMO are labelled on the left with a letter indicating the type of equation. L, R, A and T equations have been discussed representing, respectively, level equations, rates, auxiliaries and tables. The remaining equation type is labelled N.

The primary use of the N equation is to assign an initial value to a level variable. The N equation usually makes the most sense if it is placed in the model listing right after the level equation to which it corresponds. The following is an example:

$L POP.K = POP.J + DT * (BR.JK - DR.JK)$
 $N POP = 8.6E6$

Where: $8.6E6 = 8\,600\,000$ people

Constants

Once a model has been properly conceptualized and formulated in terms of levels, rates and auxiliaries, computer simulation can be done and output produced. Numerous tests are then performed on the developed model to evaluate its quality and validity. The model then is used to test alternative policies that might be implemented in the system under study.

¹² *Ibid.*, p.80.

WHY SYSTEMS DYNAMICS IN ZIMBABWE PLANNING?

The Systems Dynamics approach can be followed in the same manner to tackle the Zimbabwean economy. The Zimbabwean population growth rate is so high that it can inhibit the growth and sustainability of the economy. The question of determining what levels of population are compatible with sustainable development has to be solved.

National, political and economic objectives, together with population growth create resource requirements for industrial development and agricultural output. The resources required are not just human but also physical resources. Whether these resources can be released at rates sufficient to match requirements as projected standards of living is not easy to determine in the long term using traditional economic techniques, since long-term future costs are indeterminable.

Forrester refers to the Systems Dynamics methodology as an approach "that combines the strength of the human mind and the strength of today's computers in order to understand complex, multi-loop feedback systems of which social systems are an example".

Thus the Systems Dynamics approach will be used as a methodology to quantify the interactions between population, resources, environment and development over the long term, with population as the prime mover.

The economy of Zimbabwe can thus be structured into different sectors. A model can be formulated once all the information is gathered. After evaluating the model, policies set by the Government can be tested on the future development of the country.

DIFFERENCES BETWEEN SYSTEMS DYNAMICS AND THE TRADITIONAL ECONOMIC TECHNIQUES

R.H. Day writes:

In Systems Dynamics vocabulary, diagrammatic illustrations and language for model descriptions are used, which on the surface appear to be much different from those used by many other students of social and economic systems.¹³

While much of the use of mathematical models is used, one rarely sees familiar mathematical notation in the work. Instead it is written in DYNAMO computer language to facilitate simulating a complex system with as little explicit use of mathematics as possible.

In practice system dynamists rarely, if ever, formulate differential equations. Instead they construct a chart called a flow diagram in which all variables and their interconnections are specified. But the result is an exact graphical analogue of a system of differential and definitional equations. Thus one advantage of using Systems Dynamics is that it increases the number of variables and equations, through the construction of a flow diagram which clearly shows all variables and interconnections. In this way it also possibly increases the appearance of complexity.

13 Day, R. H., "Systems Simulation on Systems Dynamics", p.202.

The Systems Dynamics approach handles complexity more easily. It is more explicit and communicable. A Systems Dynamics model can reliably trace through time the implications of any messy maze of assumptions and interactions.

The above advantage can be a disadvantage in the escalation in parameter numbers. It violates the intellectual principle of representing a given model with a few symbols as are necessary for clarity. In conducting sensitivity analysis this can be a distinct disadvantage for it escalates the items to which sensitivity must be inferred.

Explicit controls are introduced into a Systems Dynamics model by means of switches which have the effect of switching a constant or parameter from one value to another when some variable exceeds a specified threshold e.g. CLIP function.

$$V = \text{CLIP}(A, B, C, D)$$

The above clip function can be interpreted as:

$$\begin{array}{l} V = A \text{ if } C > D \\ \text{or} \\ V = B \text{ if } C < D \end{array}$$

CONCLUSION

Concepts of Systems Dynamics have been introduced in this paper. The text is composed of a method for understanding, representing and solving complex interdependent problems. Cause-and-effect thinking with causal-loop and flow diagrams have also been explained.

It is suggested that such a method could be followed in the Zimbabwean case in order to understand and solve its interdependent problems, with a view to directing the economy on a course of sustainable development in the long-term. Policy options could also be tested on the model to assess the effects of policies imposed by the Government and politicians on the economy e.g. effects on agricultural production, industrial productivity and material standard of living.

The Systems Dynamics approach is not a substitute for the traditional economic analysis. The two can both be used to come up with more effective plans.

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